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# A CdZnTe coplanar-grid detector array for environmental remediation

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## Abstract

A portable, room-temperature gamma-ray spectrometer is being developed for use in environmental remediation activities. Good energy resolution and high detection efficiency are achieved using an array of CdZnTe coplanar-grid detectors. The array is of modular design, which allows for the stacking of an arbitrary number of detectors, as well as for the easy exchange of detectors for repairs if needed. Each element of the array consists of a 1 $cm^3$ detector and low-power readout electronics. Each detector module including the electronics fits within a small footprint of 1.4 cm X 1.4 cm, thus allowing the detectors to be closely packed. A compliant detector-mounting scheme has been developed to protect the detectors from mechanical shock and vibration expected in field use. A prototype 2 X 2 array has been constructed and evaluated. The design of the detector, detector module and test results from the array are presented.

## 1. Introduction

CdZnTe has been developed over the past decade as a high-Z material suitable for room temperature gamma-ray detector fabrication. Because of the low mobility-lifetime product for holes in this material, poor energy resolution and/or low efficiency for gamma-ray detection result when simple planar detector geometry and conventional electronics are used. A number of techniques have been devised to circumvent the problem and improve spectral response. The coplanar-grid technique [1] has been successfully used to achieve good energy resolution combined with near full-volume photopeak efficiency. At the present time, the performance of coplanar-grid detectors is limited in large part by material nonuniformity. Gross material defects such as random grain boundaries can cause severe charge trapping and reduce photopeak efficiency [2]. Grain boundaries can be readily identified through visual inspection and IR transmission imaging, and they can be avoided by selective cutting. However, even single-crystal material can exhibit significant charge transport nonuniformity [2]. Therefore, additional material characterization is needed to screen materials for final detector fabrication. Obviously, the yield of good detector material decreases rapidly as the required volume increases. Our experience with current commercial CdZnTe materials indicates that a reasonable yield of good detectors can be obtained for a detector volume of 1 $cm^3$. Another factor to consider is that the noise associated with the coplanar-grid electrode structure generally increases with the detector area. Given these considerations, we have concluded that detector geometry in the form of a cube, 1 cm on a side, provides a good compromise between detector yield, noise, and detection efficiency.

For many applications, detector volumes substantially larger than 1 $cm^3$ are desired. One of these applications we are pursuing is a portable gamma-ray spectrometer for use in environmental remediation activities. To achieve the high detection efficiency necessary for such applications, we have developed a modular detector design that would allow a number of 1 $cm^3$ coplanar-grid detectors to be assembled into a two dimensional array to increase effective area and therefore detection efficiency. The design of the detector, detector module and test results from a prototype 2 X 2 array are presented.

## 2. Detector design

The principle of operation of the coplanar-grid detector has been described in past publications [1,2]. The basic configuration of the detector consists of two interdigitated grid electrodes on one surface of the detector and a full area electrode on the opposite surface. A negative high voltage is applied to the full area electrode so that electrons generated in the detector are collected towards the grid electrodes. A separate smaller bias voltage is applied across the two grid electrodes so that the electrons are collected at only one grid electrode. Signals from the two grid electrodes are processed independently with two charge-sensitive preamplifiers. The output signals from the preamplifiers are subtracted with an adjustable relative gain to give a net output signal. By adjusting the relative gain, the effect of electron trapping can be closely compensated, leading to a highly uniform detector response regardless of depth of gamma-ray interaction over most of the detector volume [2].

To maintain good spectral resolution, the detector response has to be uniform also in the lateral directions. The finite size of a detector gives rise to edge effects, which can produce significant lateral nonuniformity in detector response. Such edge effects can be greatly ameliorated through careful electrode design [3]. Fig.1 shows the design that we have adopted for the present detectors. It consists basically of a series of parallel strip electrodes interconnected to form the two interdigitated grid electrodes. Modifications to the electrode configuration were made to compensate for the edge effects. One modification was that the strip adjacent to the last one along each of two opposite edges of the detector was widened. This compensates for the edge effect due to those two sides of the detector. The two line electrodes that interconnect the strips would also introduce nonuniform response along the other two sides of the detector. Compensation in this case was achieved by adding a line electrode parallel to an interconnecting electrode and connected to the opposing grid electrode. This is similar to the design used by He et. al. [4]. To maintain a high degree of uniformity, it is also important that the gap between the outer perimeter of the electrodes and the edge of the detector be kept to a minimum. Even a gap of 1 mm would introduce significant nonuniformity. We typically keep the gap to within 0.25 mm. To accommodate slight variations in crystal size and shrinkage due to reprocessing, we produced 3 sets of masks with identical design but scaled to slightly different overall dimensions to accommodate crystals with areas ranging from 9.5 mm X

9.5 mm to 10 mm X 10 mm. A guard ring is deliberately avoided since our modeling results have indicated that this would create substantial lateral nonuniformity in the charge induction properties of the detector, thereby degrading energy resolution and spectral line shape.

Fig. 2a shows a $^{137}Cs$ spectrum obtained from a 1 $cm^3$ coplanar-grid detector made using the grid pattern of Fig. 1. The photopeak exhibited a near gaussian line shape with a FWTM/FWHM of 2.03. Fig. 2b is an early spectrum taken with a different 1 $cm^3$ that has a simple grid design with no edge compensation. The broadening seen near the base of the photopeak is attributed to nonuniform detector response due to uncompensated edge effects. The pulser peak in Fig. 2a has a width of 10.6 keV, which contributes substantially to the photopeak resolution. Subtracting this contribution yields a net resolution of 1.35%. This implies that the material uniformity is very good, and also indicates that the present grid electrode design gives a highly uniform detector response.

## 3. Detector module

The CdZnTe crystals used in this work were all obtained from eV Products. The crystals were supplied as 1-cm cubes, and they were selected to be free from random grain boundaries, although most of them do contain twins. Prior to coplanar-grid detector fabrication, each crystal was fabricated into a simple planar detector, and the electron transport uniformity was evaluated using alpha particles [5]. Detectors exhibiting good uniformity were then reprocessed into coplanar-grid detectors. Evaporated Au contacts were used on all the detectors. The grid electrode patterns were formed using shadow masks.

To allow the assembly of a two-dimensional array of detectors in a close-pack geometry, a detector module with a small footprint was developed. The module has a 1.4 cm X1.4 cm frontal area and is 6 cm in length (Fig. 3). It consists of a detector mount and an electronics assembly. For field applications, the detectors will be subjected to mechanical vibration and shock. A compliant mounting scheme was therefore developed to minimize the chance of mechanical damage to the detectors. As shown in Fig. 3, the detector was installed inside a Lexan cup. There exists a small clearance between the detector's side surfaces and the inside wall of the cup. The detector was secured in the Lexan cup using silicone rubber adhesives, which were injected through holes along the sides until they came into contact with the edges of the detector. After the silicone rubber was cured, the detector became suspended by the silicone rubber, which serves as the mechanical isolation. Three feedthroughs at the back of the Lexan mount provide electrical connections to the two grid electrodes and the full-area electrode. Connections between the feedthroughs and the detector electrodes were made using gold wires and conductive epoxy.

The electronics consists of two small circuit boards assembled back-to-back, which contain two charge-sensitive preamplifiers and a signal subtraction circuit to implement the coplanar-grid charge sensing scheme. The circuit boards are secured to a Lexan frame, which was then fastened to the back of the detector mount. The whole electronics assembly fits within the footprint of the detector mount. The differential gain adjustment for optimizing the detector response is made via a miniature potentiometer accessible through an opening on the side of the Lexan frame. The electronics runs on a power supply of +/- 6V with a total power consumption of 120 mW per detector. The noise of each preamplifier alone (without any detector connected and before signal subtraction) is 180 e rms at a shaping time of 2 μs. Much of the noise is due to the use of relatively low-value load resistors (20 MΩ) that are needed to accommodate the leakage current of the detector. With the load resistors removed, the noise of the preamplifier decreases to 96 e rms.

Included in the electronics assembly is a high voltage filter and a voltage divider to derive the grid bias from the main detector bias. The ratio of the divider was chosen to provide the appropriate grid bias when the full detector bias is applied. Therefore, only one bias voltage is needed to operate the detector.

## 4. Detector array

Four detector modules were fabricated. The photopeak efficiency of each detector was measured separately using 662 keV gamma rays from a NIST traceable standard $^{137}$Cs source. The source was located at 20 cm from the front surface of the detector to approximate parallel beam illumination. Signals from the detector module were processed using a conventional shaping amplifier and a MCA. Three of the detector modules operated at -1400 V bias, and one operated at -1300 V bias. The differential gain of each detector module was adjusted to give the best energy resolution. The measured photopeak counts for the four detectors amount to 7.2%, 7.2%, 6.5% and 6.4% of the number of incident 662 keV gamma rays. The gamma-ray flux at the detector was calculated assuming a point source at a distance of 20.5 cm, which is the distance between the source and the midpoint of the detector. Monte Carlo simulations showed that the fraction of incident 662 keV photons (parallel beam) that deposit full energy in a 1 cm cube CdZnTe crystal (10% Zn, 5.8 gm/cm$^3$) is 7.7%, taking into account the escape of Compton and photoelectrons [6]. This gives a relative photopeak efficiency of 94%, 94%, 84% and 83% for the four detectors. A small loss in photopeak efficiency is expected for a coplanar-grid detector because of the strong variation in detector response in the near-grid region. This region has a thickness comparable to the strip pitch of the grid electrodes, which is 0.5 mm for the present design. Events occurring within this region will generate substantially reduced signals and these will be distributed below the photopeak. Also, the actual size of each detector is slightly less than 1 cm$^3$ due to material loss during processing. With these considerations, the 94% relative efficiency obtained for the two detectors is probably close to ideal. The detector with 83% relative efficiency is known to have a small random grain boundary that traps electrons. Events occurring in the region between the grain boundary and the cathode will have greatly reduced signals and thus would not contribute to the photopeak. The detector with 84% relative efficiency did not appear to have any significant random grain boundary. Each of the detectors contains a few twin planes.

The four detector module was assembled to form a 2 X 2 array, which was installed into an aluminum enclosure (Fig 4). Signals from the four detector modules were passed outside the enclosure and processed through four shaping amplifiers, a multiplexer and a MCA. A shaping time of 2 μs was used. Fig. 5 shows the spectral performance of each of the detectors obtained separately with a $^{137}$Cs source and a $^{57}$Co source. The FWHM at 662 keV ranges from 2.5% to 3.0%. The resolution at 122 keV is dominated by electronic noise, which was in large part associated with the coplanar-grid electrodes.

In actual operation, the four spectra can simply be summed to get a total spectrum. However, some improvements in peak to background can be expected if the signals were acquired in anti-coincidence mode, in which an event is rejected if signals were detected simultaneously in two or more detectors. These events are likely gamma rays that Compton scatter from one detector and interact in the other detectors. Rejecting these events should lead to a reduction in the Compton background. Alternately, instead of rejecting these events, one could sum the amplitudes of the signals that occur in coincidence to recover the full gamma ray energy. This summed coincidence mode should enhance the photopeak efficiency compared to the simple summing of individual spectra.

To compare these different modes of operation, the shaped signals from the four detectors were digitized simultaneously whenever any one or more of the detectors showed an event. For each event, the digitized amplitude information from the four detectors was saved in a computer. The data was then processed off line to create spectra using the different summing modes. Fig. 6 (top) compares the spectra obtained using the simple summing and the anti-coincidence modes. A slight reduction in the Compton background can be seen. In the summed coincidence mode, a small increase in photopeak counts is observed in addition to the reduction in Compton background (Fig. 6 bottom). However, the improvements obtained were slight. This is due to the unfavorable geometry of the small array. Only a small fraction of the scattered gamma rays from a detector intersect the other three detectors, and just a fraction of those will be detected. A larger array would give a more favorable geometry and should give a much higher level of improvements.

**5. Conclusions**

The results from the 2X2 array of coplanar-grid CdZnTe detectors indicate that gamma-ray detectors with good energy resolution and high efficiency can be realized by arraying multiple detectors. The modular design developed in this work allows an arbitrary number of detectors to be assembled, as well as enables the easy interchange of detectors if needed. The small footprint of the module permits close packing of detectors. Improvements in Compton background and photopeak efficiency using anti-coincidence and summed coincidence were demonstrated. Construction of a much larger detector array should be possible using the same modular design to achieve higher detection efficiency or to provide imaging capability.

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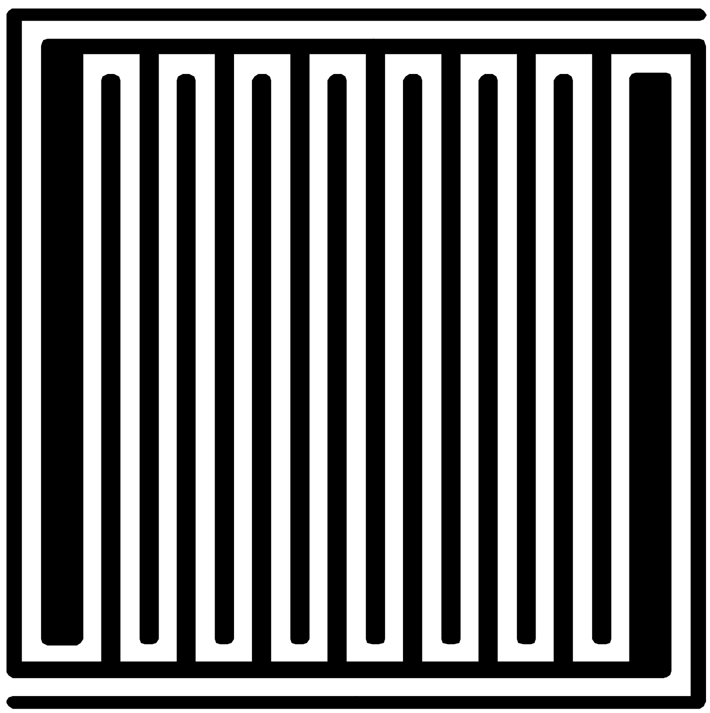

Fig. 1.  Coplanar-grid electrode pattern with edge compensation.

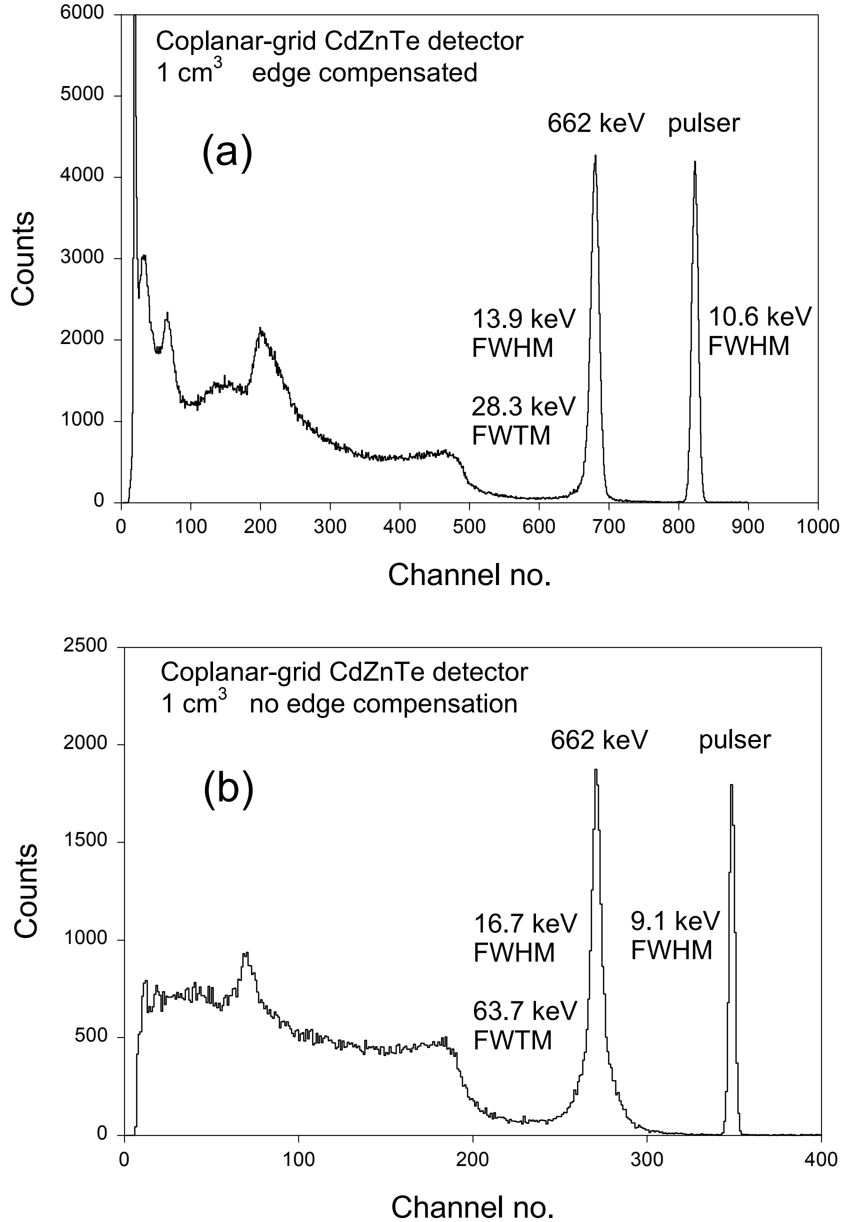


Fig. 2. $^{137}$Cs spectrum obtained from (a) a 1 cm$^3$ coplanar-grid CdZnTe detector with edge-compensated grid electrodes and (b) another 1 cm$^3$ detector with no edge compensation.

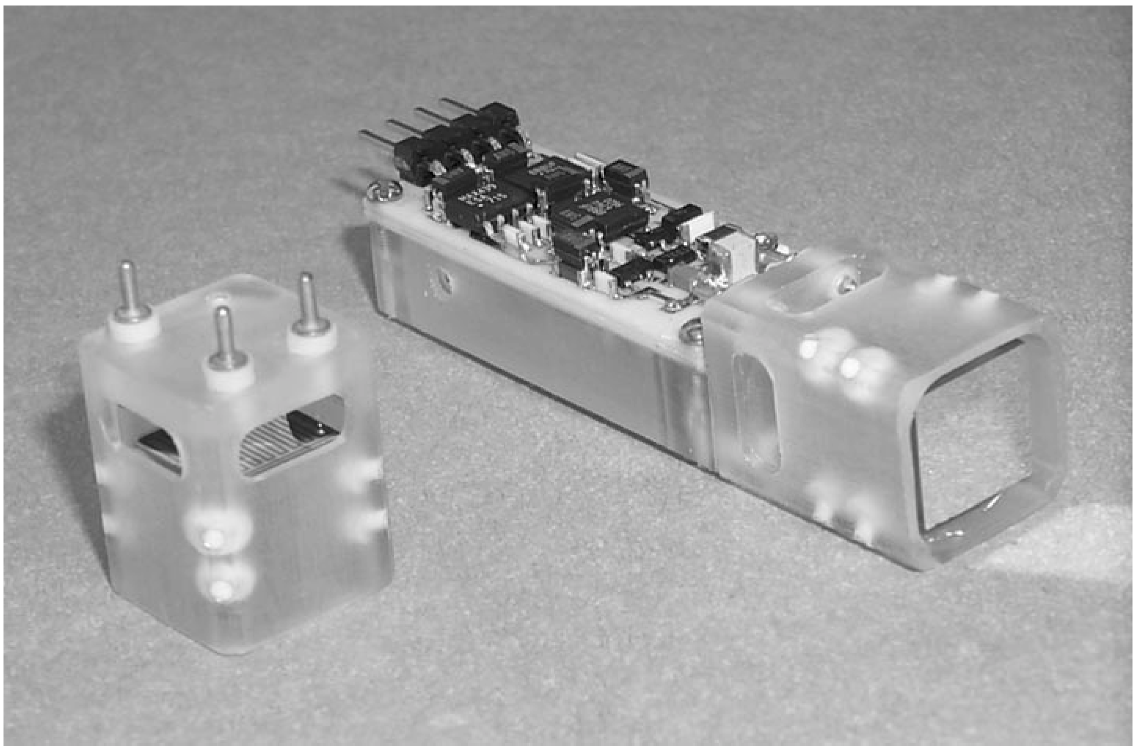

Fig. 3. A 1 $cm^3$ CdZnTe coplanar-grid detector mounted in a Lexan cup (left) and integrated with the electronics assembly to form a complete detector module (right).

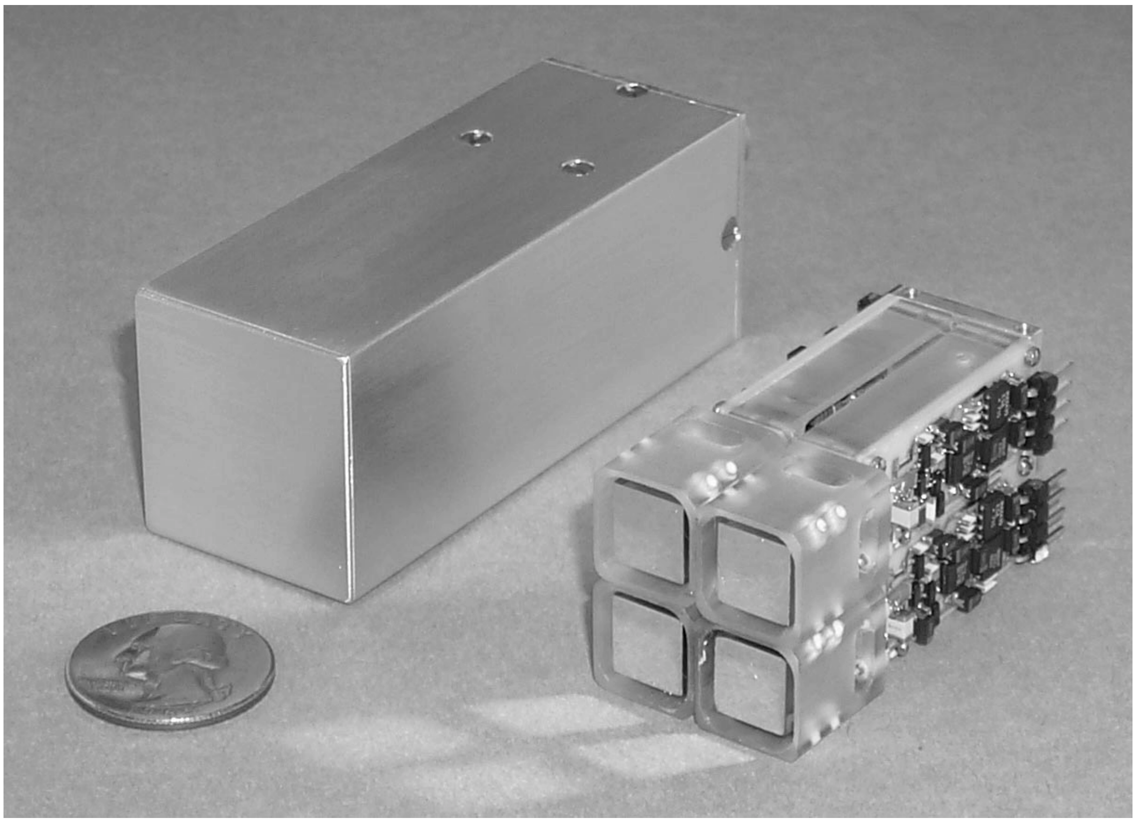

Fig. 4.  A 2X2 array assembled from four detector modules.

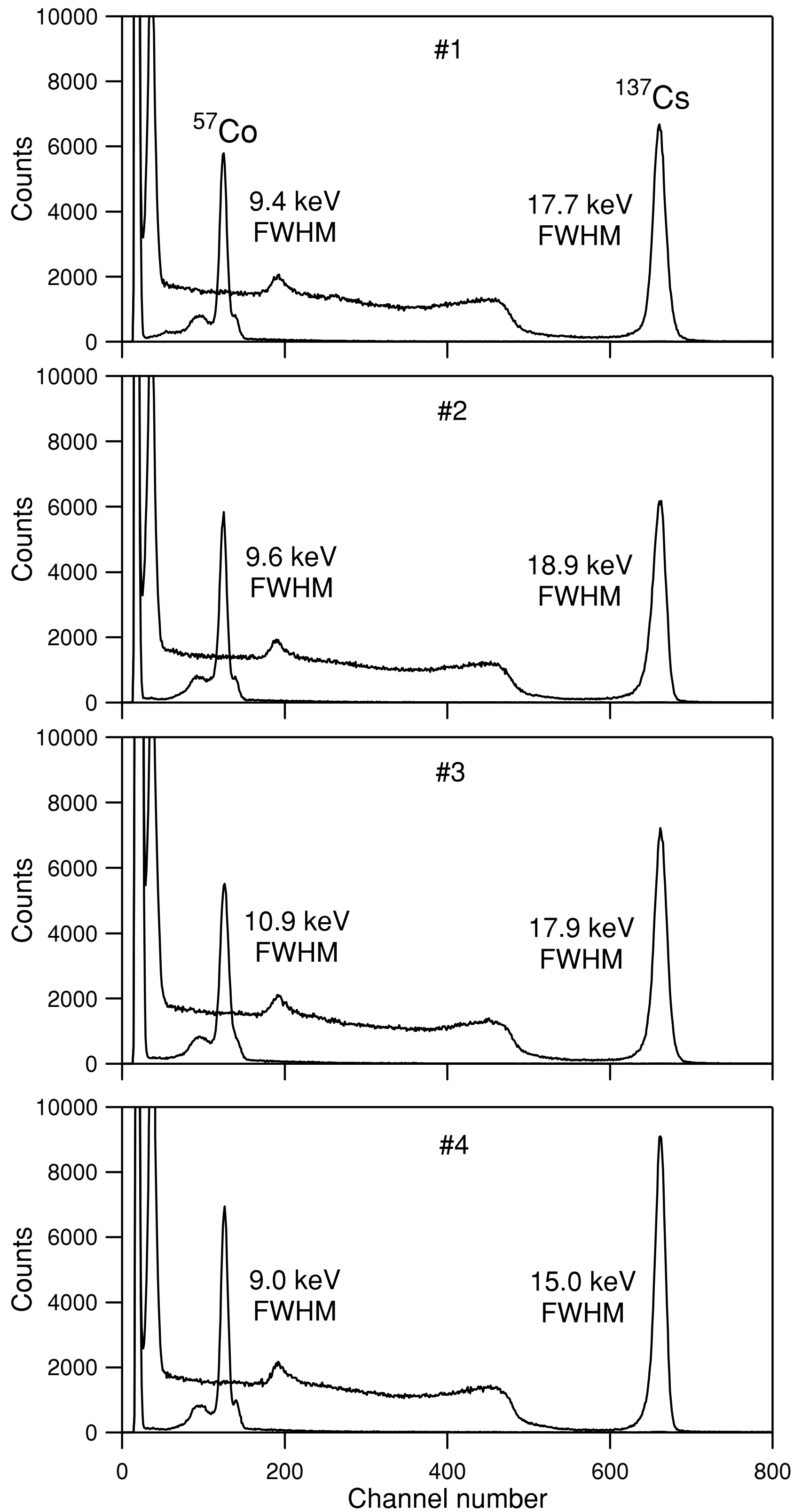


Fig. 5. $^{57}$Co and $^{137}$Cs spectra obtained from each of the four detector modules.

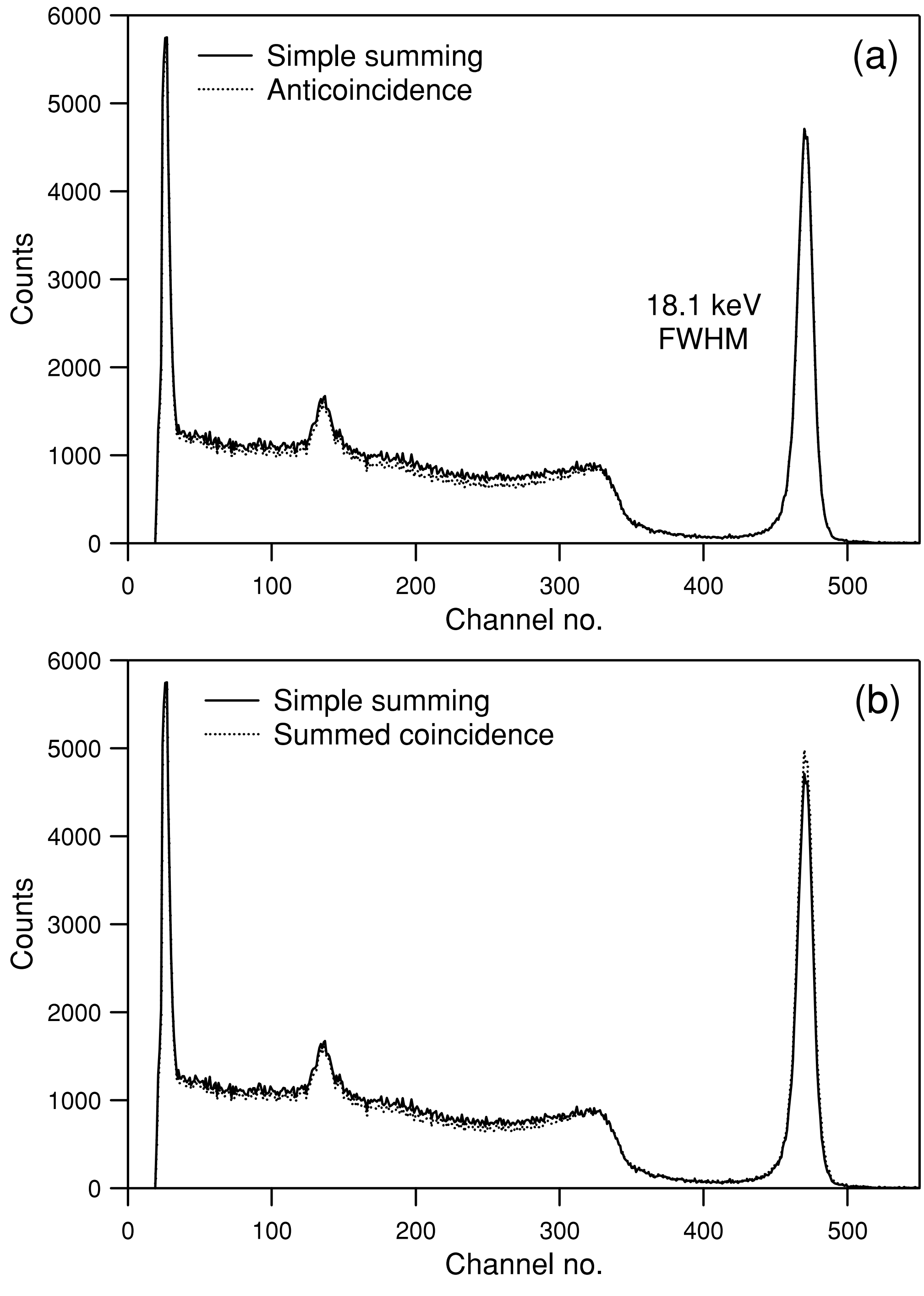


Fig. 6. Comparison between simple summing and anticoincidence modes (top) and between simple summing and summed coincidence modes (bottom) for combining signals from the four detectors in the 2 X 2 array.